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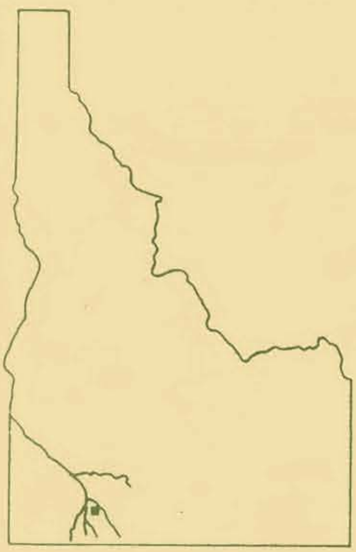
PNE-526
FINAL REPORT

MASTER

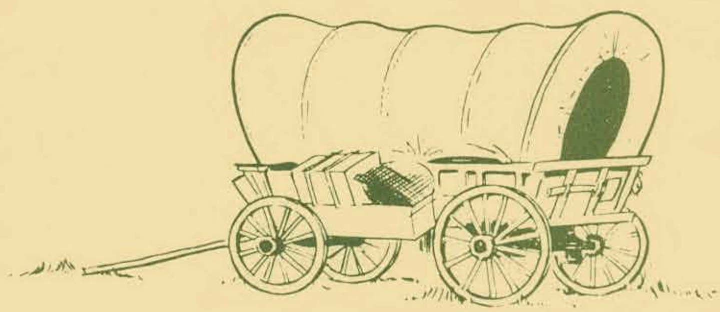
Plowshare civil, industrial and scientific uses for nuclear explosives

UNITED STATES ARMY CORPS OF ENGINEERS

BRUNEAU PLATEAU, IDAHO
30 September 1965



PROJECT SCHOONER



Ecological and Environmental Effects From Local Fallout from Schooner 1. Soil Thermoluminescence in Relation to Radiation Exposure Under Field Conditions

UCLA, Lab. of Nuclear Medicine and Radiation Biology,
and
E G & G, Inc.

ISSUED: FEBRUARY 27, 1970

P4581

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PNE-526

NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS (TID-4500)

PROJECT SCHOONER

PROJECT CEP-68.5

ECOLOGICAL AND ENVIRONMENTAL EFFECTS FROM LOCAL FALLOUT FROM SCHOONER

1. SOIL THERMOLUMINESCENCE IN RELATION TO RADIATION EXPOSURE UNDER FIELD CONDITIONS

By

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This work was performed under Contract No. AT(29-1)-1183 between EG&G, Inc. and the Environmental Sciences Branch, Division of Biology and Medicine, Atomic Energy Commission and under Contract No. AT(04-1) GEN-12 between the University of California, Los Angeles, and the Environmental Sciences Branch, Division of Biology and Medicine, Atomic Energy Commission.

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ACKNOWLEDGMENTS

The authors express their grateful appreciation to the following people who have assisted in the various aspects of this work.

EG&G, Inc., Santa Barbara Division

Dr. A. D. Kantz

Mr. T. M. DeVore

Laboratory of Nuclear Medicine and Radiation Biology, University of California, Los Angeles, California

Dr. E. M. Romney

Mr. M. Hamilton

Mr. J. D. Childress

Mr. P. A. T. Wieland

Mr. T. L. Ackerman

Mr. H. M. Mork

ABSTRACT

A study was conducted to determine whether or not soil thermoluminescence could be related to radiation exposure in the field under conditions of actual nuclear detonation. The correlation coefficients between TLD-100 LiF dosimeter determinations and soil thermoluminescence for noncalcareous and slightly calcareous soils were 0.93 and 0.89, respectively. These results suggest that soils might be used to estimate the radiation exposure received by a given area. With a highly calcareous soil studied, the correlation coefficient (0.78) was poorer, indicating the lower suitability of this type of soil.

Since soils exhibit variable amounts of "natural" thermoluminescence, pre-irradiation soil sample collection appeared to be necessary. This pre-irradiation sample might then be used to determine the amount of "natural" thermoluminescence and the "equivalent" exposure level by irradiating it with a known radiation source. ~~The applicability of these procedures, however, remains to be tested.~~ 3 references (auth)

CONTENTS

ILLUSTRATIONS

I. INTRODUCTION

Project SCHOONER was a nuclear experiment in a layered tuffaceous medium executed as a part of the Plowshare Program for development of nuclear excavation. SCHOONER was detonated on 8 December 1968 at 0800 (PST) in Area 20 Nevada Test Site (NTS). The resultant yield was 31 ± 4 kt. Other details will be, or have been published elsewhere. This paper is concerned only with the soil thermoluminescence resulting from exposure to radioactivity from the local fallout dispersed by this detonation.

1.1 BACKGROUND AND RATIONALE

The detection and measurement of ionizing radiation have long been a matter of considerable study to the physical and the life sciences. Over the years, considerable degrees of sophistication have been attained toward precise dosimetry using various means. At present, there are several appropriate dosimeters that may be used in the field. Among these are the thermoluminescent dosimeters. These dosimeters are presently being used in a gamma radiation field established to study the effect of radiation on a desert ecosystem (Rock Valley, Nevada Test Site). In such a radiation field, the dosimeters can be placed at the selected sites before exposure to radiation. The pre-irradiation placement, however, may not have been done always at the appropriate sites or in sufficient number to fully assess the radiation field. Also, small variations in the terrain may alter the exposure field. In areas exposed to an unexpected nuclear detonation, pre-irradiation placement of dosimeters certainly will not have been done. Under these circumstances, it may be advantageous if the soil or other materials in the environment could be used to estimate the radiation exposure. The senior author has been involved in studying the factors that influence soil thermoluminescence, in order to determine whether or not soil can be used as a radiation dosimeter (2, 3).

1.2 OBJECTIVE

The objective of this study was to determine whether or not soil thermoluminescence could be related to radiation exposure in the field under conditions of an actual nuclear detonation.

2. PROCEDURE

Thermoluminescence was measured on soils exposed to radiation from local fallout from the SCHOONER event. In this operation a series of 100 dosimetry stations were established in the bottoms of the canyons which roughly encircle the ground zero at distances of 5,000 to 6,000 feet. The precise locations and the description of each station will be given in detail by Rhoads et al. in a later report. Figure 1 is a photograph showing several of the dosimetry stations and a portion of the terrain in the experimental area. Each dosimetry station is marked by a steel stake. The ground zero was located in the direction to the right of the photograph.

Three soils were exposed to radiation at each station. Two of the soils were of known chemical and physical characteristics, which are given in Table 1. Hanford sandy loam is an agricultural soil collected in California. Soil No. 4FF is a non-saline calcareous soil collected at Frenchman Flat (Nevada Test Site). The third soil was the native soil (0-1 inch deep) collected at the site of each dosimeter station. In order to obviate contamination by radioactive fallout, these soils were placed in polyethylene plastic bags (0.025 mm thick) in approximately 20-gram aliquots. At each station, one bag of each soil was left exposed on the surface, while another bag of each soil was buried 4 inches deep in the native soil. These bags of soils were left in the radioactive fallout field for 12 days beginning on D-day. During this exposure period, over 90 per cent of the infinity dose will have been received by the soils (1). The thermoluminescent decay rates of the soils were less than one per cent during the period of analysis.

The measurements of the intensities of the emitted light as a function of temperature (glow curve) of the soils were done by the apparatus shown in the block diagram (Fig. 2). The sample heating and the light sensing systems were fabricated in our laboratory. The samples were heated directly on the heater, which was made of stainless steel plate (2.5 mm thick) with a circular recess (17.5 mm dia. X 1.3 mm depth) for holding the sample. The chromel-alumel thermocouple was silver soldered on to the plate. The Hewlett-Packard (Model 240 M) temperature programmer provided for various heating rates that were linear from ambient to around 500°C. All of the present results were obtained by using a heating rate of 500°C per minute. All sample heating was done in argon atmosphere (flow rate: 1 liter/min.).

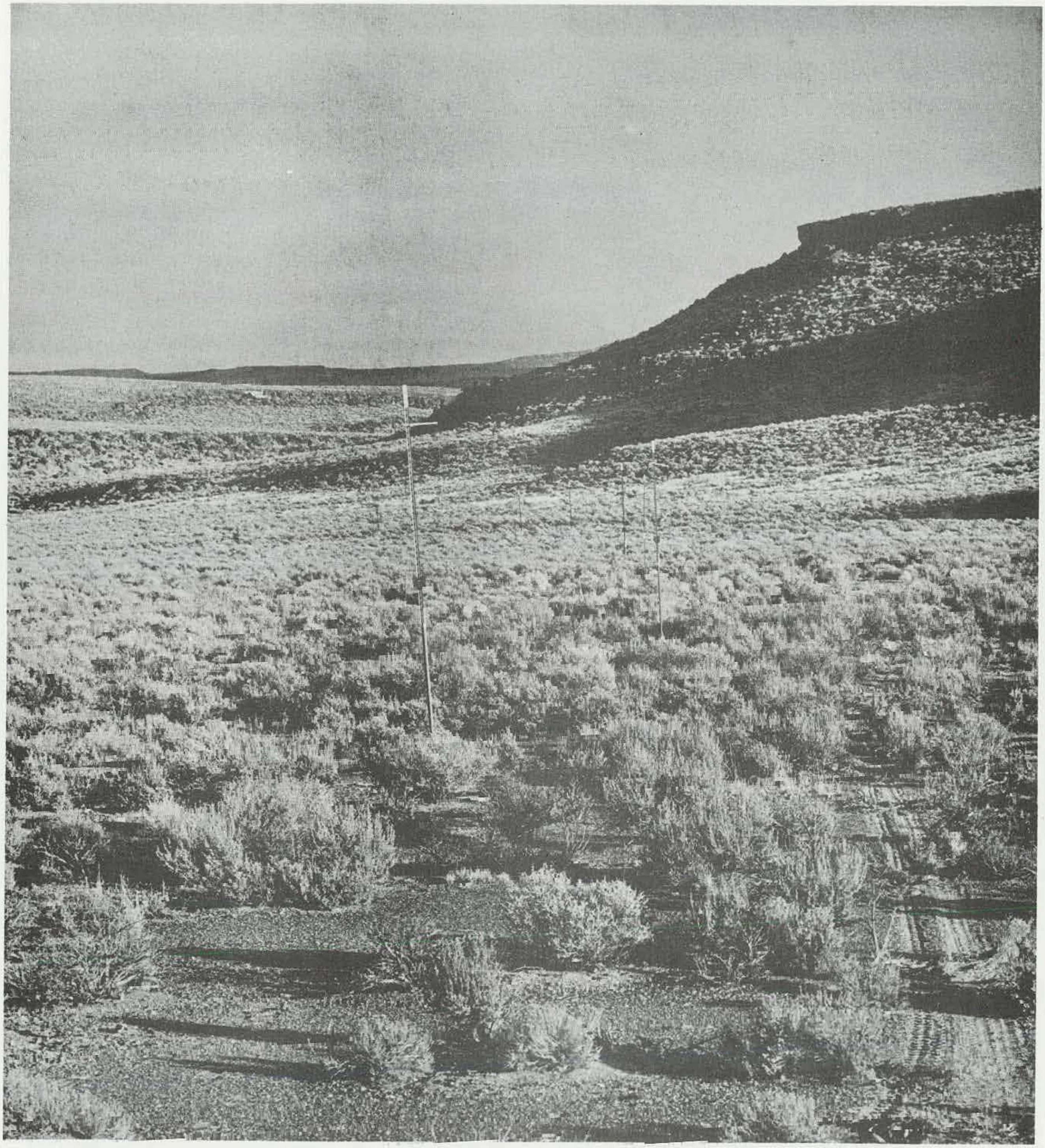

Fig. 1. Photograph of a portion of the terrain in the experimental area.

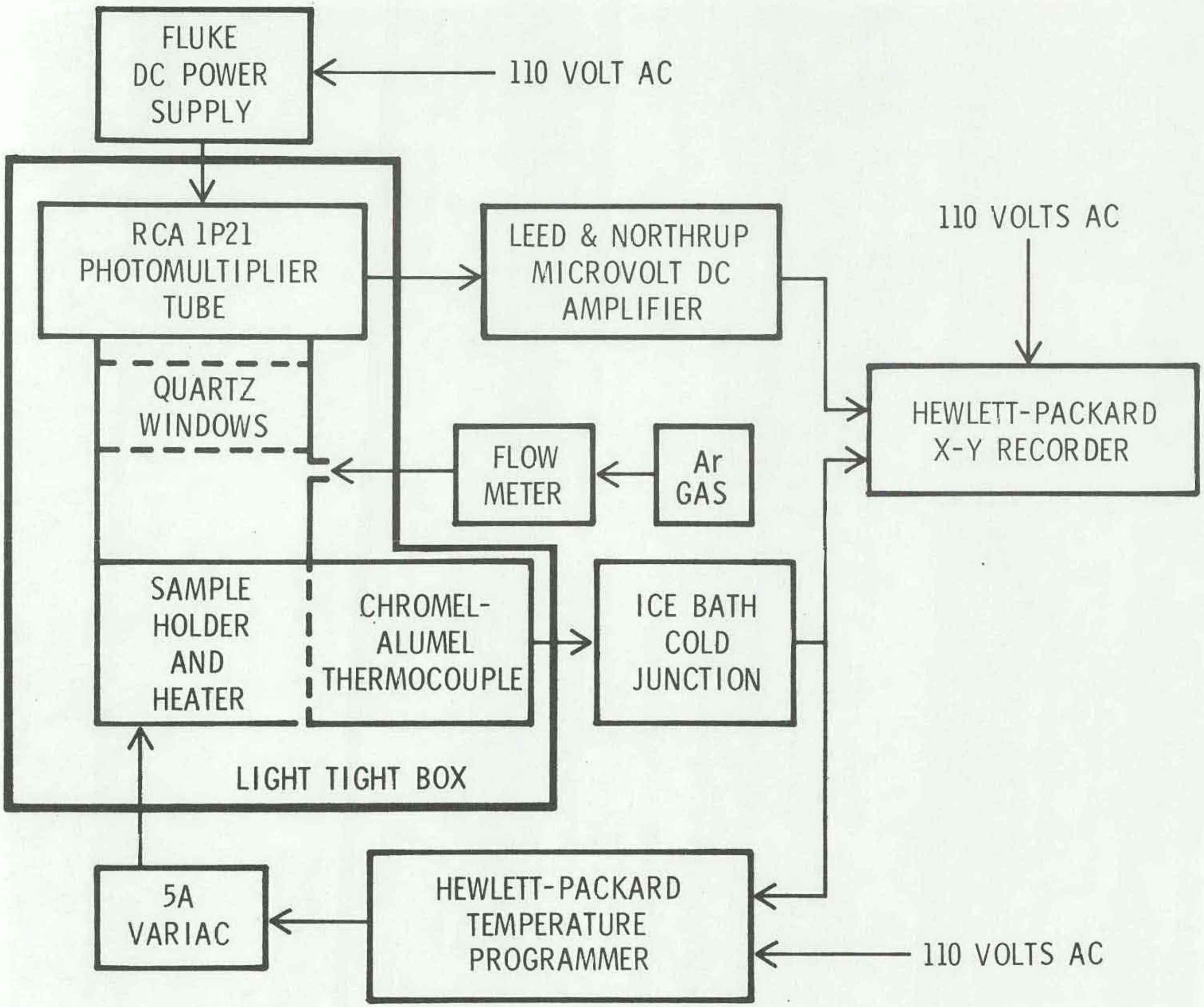

Fig. 2. Block diagram of the thermoluminescence apparatus.

Table 1
Chemical and Physical Properties of Soils

Properties		Soil	
		Hanford sandy loam	No. 4FF
pH (1=1 suspension)		5.60	8.62
Lime (as $CaCO_3$)	%	0.00	33.00
Organic matter	%	1.99	0.45
Cation exchange capacity	me/100g	7.60	9.98
Extractable cations*			
Na	me/100g	0.21	0.48
K	me/100g	0.72	2.32
Mg	me/100g	1.40	6.58
Ca	me/100g	5.23	83.56
Dominant clay mineral**		I	M
Particla size distribution			
Sand	%	66.08	74.45
Silt	%	26.54	16.60
Clay	%	7.37	8.95

*Extractable by neutral normal ammonium acetate

**I = illite, M = montmorillonite

Thirty milligrams of loose sample, which was spread over the entire area of the receptacle, was used for each determination. The glow curve for each sample was corrected for black body radiation, which varied somewhat with the soil, but usually occurred in the temperature range of 350° to 400°C. It was determined by making a second run on the sample after cooling it to room temperature without disturbance.

The radiation exposure at 4-inch depth in the soil was determined with extruded (1.0 mm dia. X 6 mm) LiF (TLD-100) rods obtained from the Harshaw Chemical Company. These rods were in gelatin capsules placed in one of the bags of soils that were buried at each site. The calibration curves for the rods were obtained by exposing them to various amounts of Cs137 gamma rays in air. As a standard operating procedure, the rods were annealed for 1 hour at 400°C and then for 24 hours at 70°C before irradiation. A post-irradiation annealing regimen (100°C for 10 minutes) also was used for both the calibration and the unknown exposure determinations in order to minimize the influence of fading during exposure and storage. All TLD-100 rods were read out on a reader (Model S-2LC) purchased from Madison Research and Development Laboratories, Inc. Since all readings of the exposures in the soil were referred to the calibration curves obtained in the manner described above, the word exposure as used in this paper indicates "exposure in roentgens referred to air."

3. RESULTS

3.1 RADIATION EXPOSURES TO TLD-100 DOSIMETERS

Figure 3 shows the radiation exposures to the TLD-100 rods that were buried four-inches deep in the soil at the different dosimeter stations. These exposures were due only to gamma photons, since the beta radiation was virtually shielded out by the soil. In general, three principal zones of radioactive fallout contamination occurred along the arc of the dosimeter stations. The peaks of these zones occurred at stations No. 34, 10, and 6N. The greatest exposure (546 R) occurred at station No. 6N, which was 11 degrees east of north from ground zero. Stations No. 34 and 10 were located 56 and 30 degrees east of north, respectively.

3.2 "NATURAL" THERMOLUMINESCENCE OF SOILS

Soils exhibit "natural" thermoluminescence, because they are bombarded by cosmic rays and because they contain naturally occurring, long-lived radionuclides such as K40, Rb87, C14, and the members of the uranium and thorium families. The amount of "natural" thermoluminescence is dependent on the soil composition. For example, the calcareous soils show much greater "natural" thermoluminescence than the non-calcareous soils (2). In the present study, the relatiye "natural" glow intensity of the non-calcareous Hanford sandy loam was 5.7 while that of the highly calcareous soil No. 4FF was 214.7. The variation of "natural" thermoluminescence of the soils collected at 79 dosimeter stations that showed measurable induced thermoluminescence are shown in Figure 4. The relative glow intensity of these soils ranged from 9.1 to 29.5. The lime content of these soils ranged from 0.02 to 1.90 per cent with a mean and standard deviation of 0.18 ± 0.33. In the results shown below, the "natural" thermoluminescence of each soil has been subtracted from the total thermoluminescence after exposure to radioactive fallout. The difference is designated as the "induced" thermoluminescence in this paper.

3.3 INDUCED THERMOLUMINESCENCE OF SOILS

The thermoluminescence induced in the surface and subsurface soils as a result of exposure to radioactive fallout at different dosimeter stations is shown in Figures 5 through 7. A comparison of the results for the subsurface

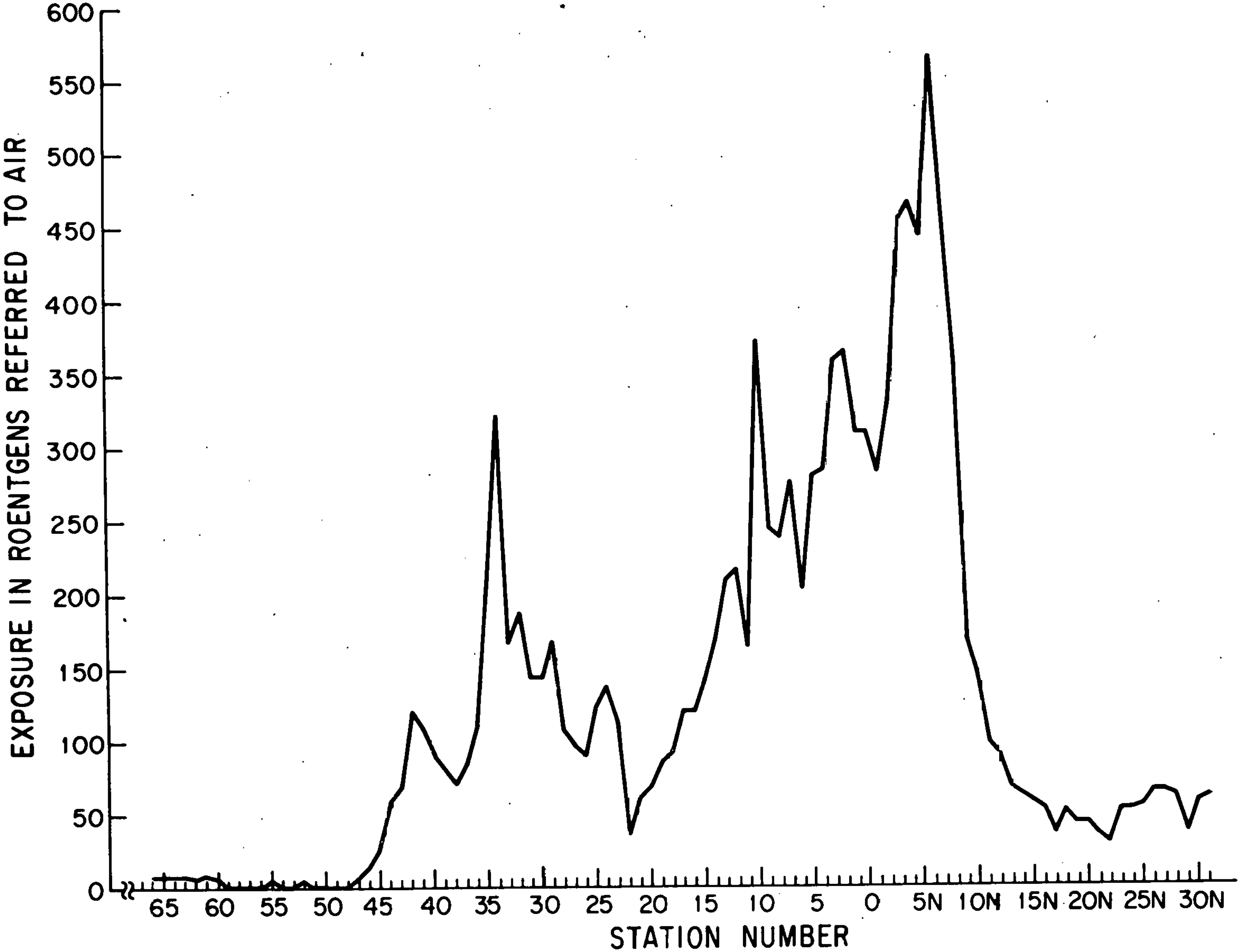

Fig. 3. Radiation exposures to the LiF (TLD-100) rods that were buried four inches deep in the soil at different dosimeter stations.

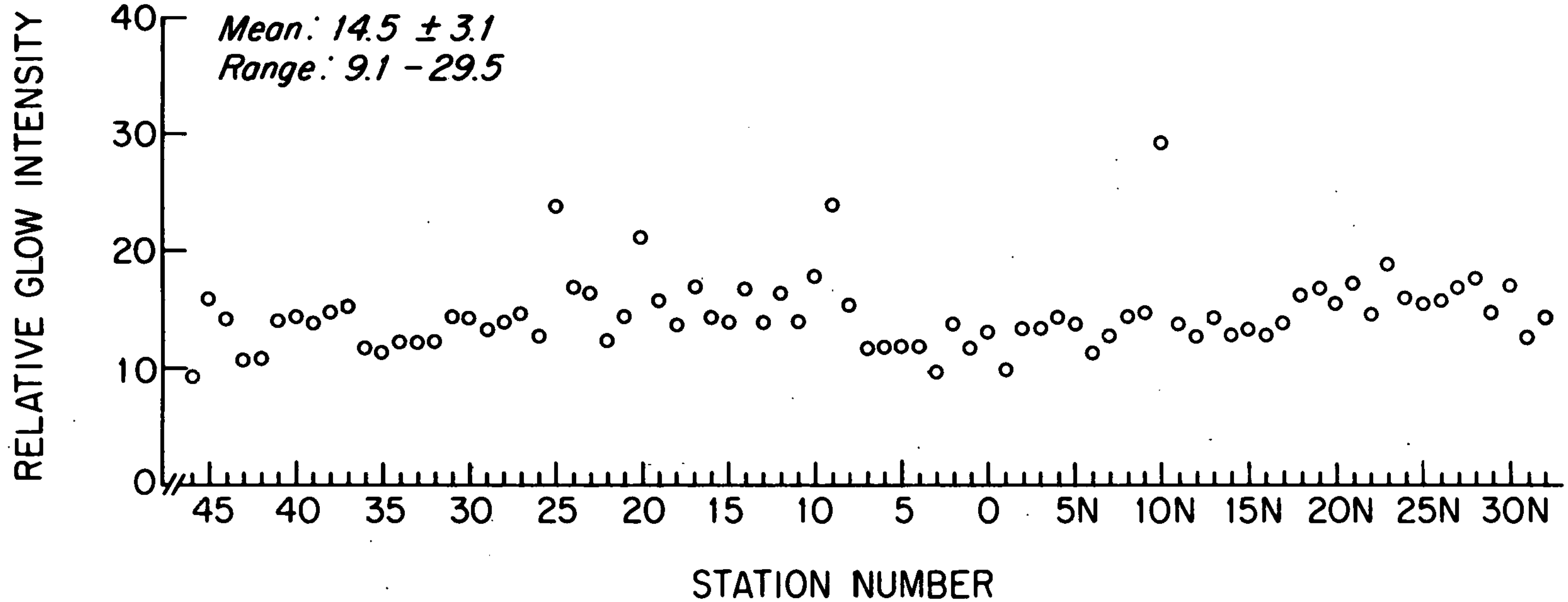

Fig. 4. "Natural" thermoluminescence of the native soil at each dosimeter station.

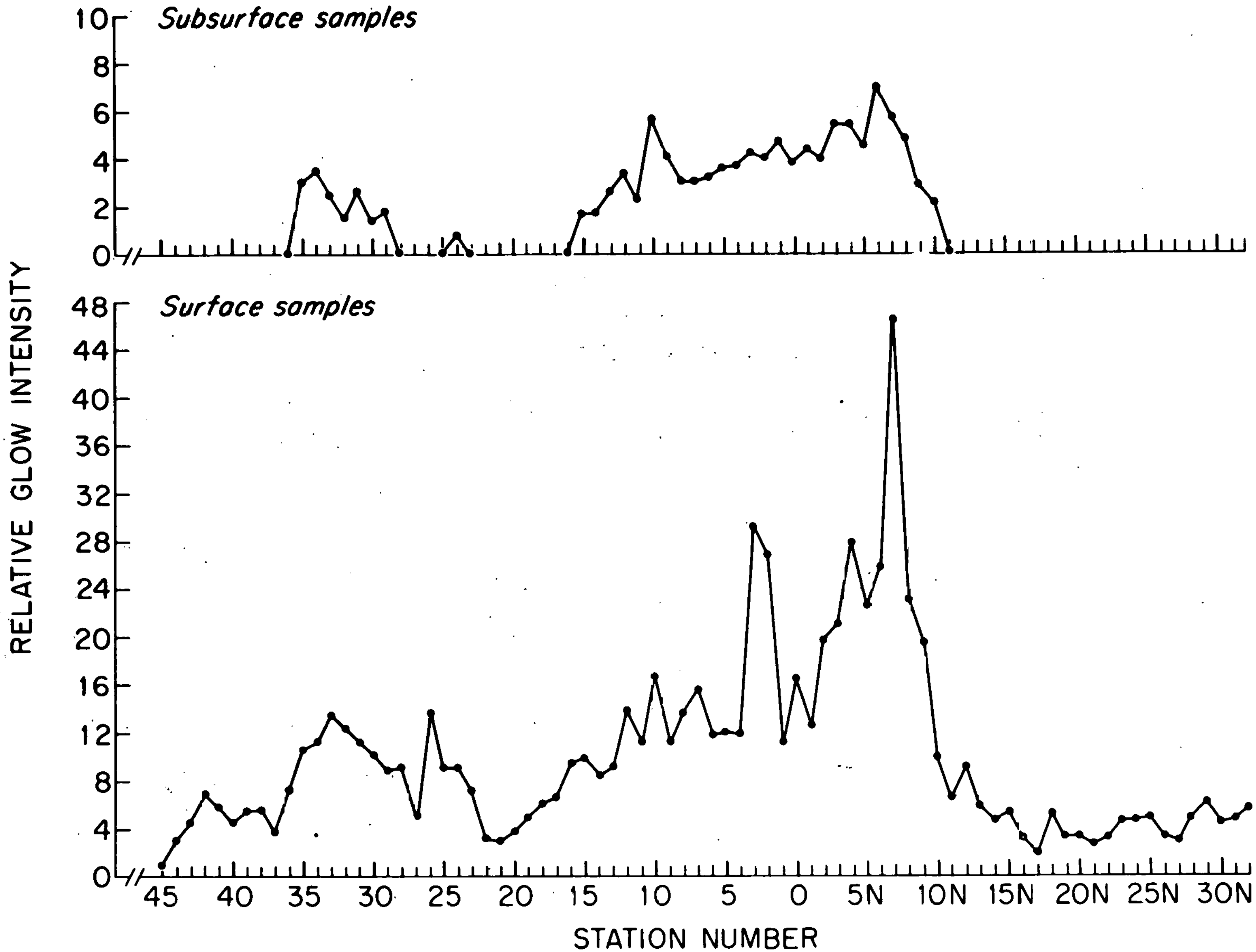

Fig. 5. Thermoluminescence induced in surface and subsurface samples of Hanford sandy loam at each dosimeter station.

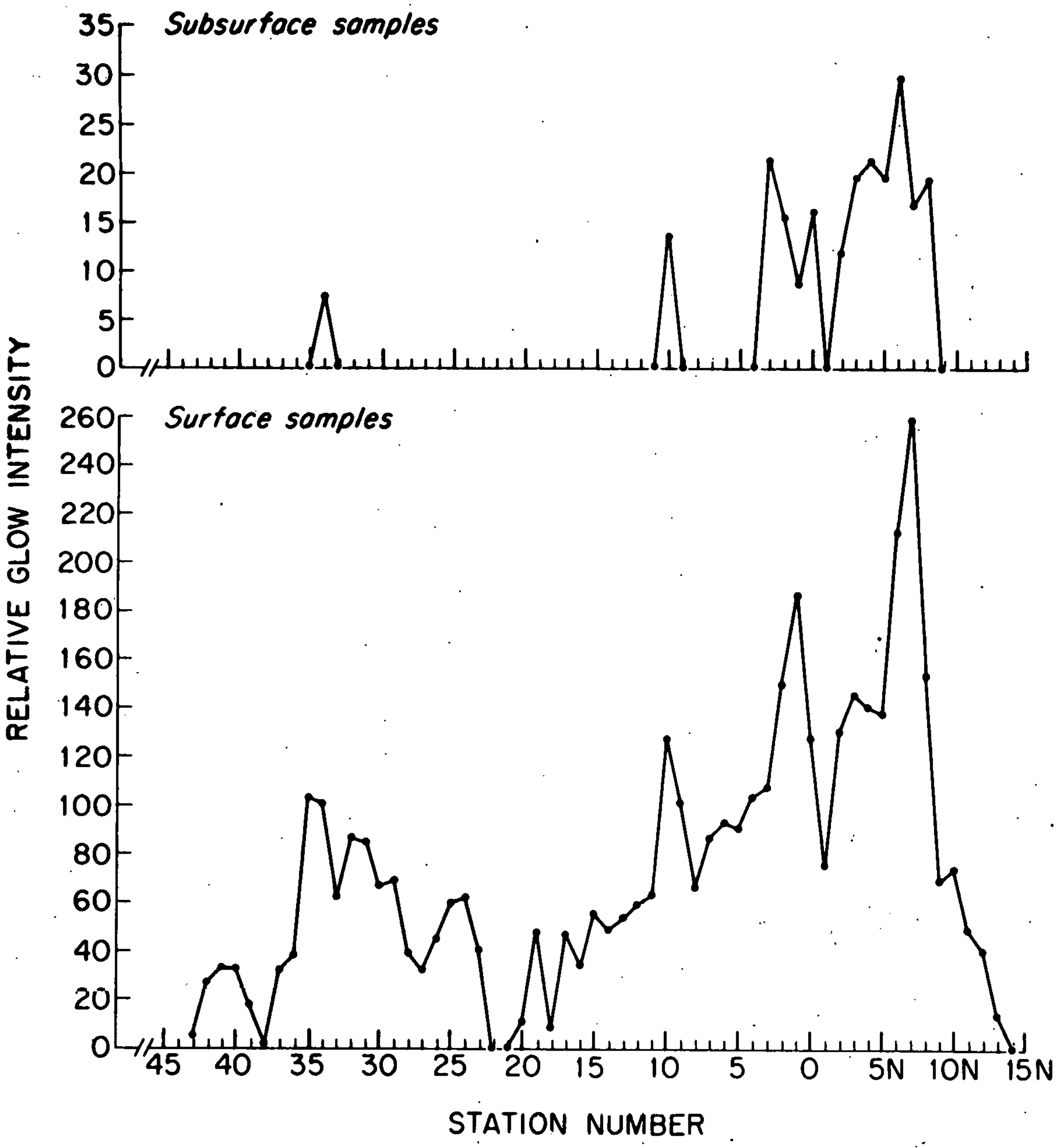

Fig. 6. Thermoluminescence induced in surface and subsurface samples of soil No. 4FF at each dosimeter station.

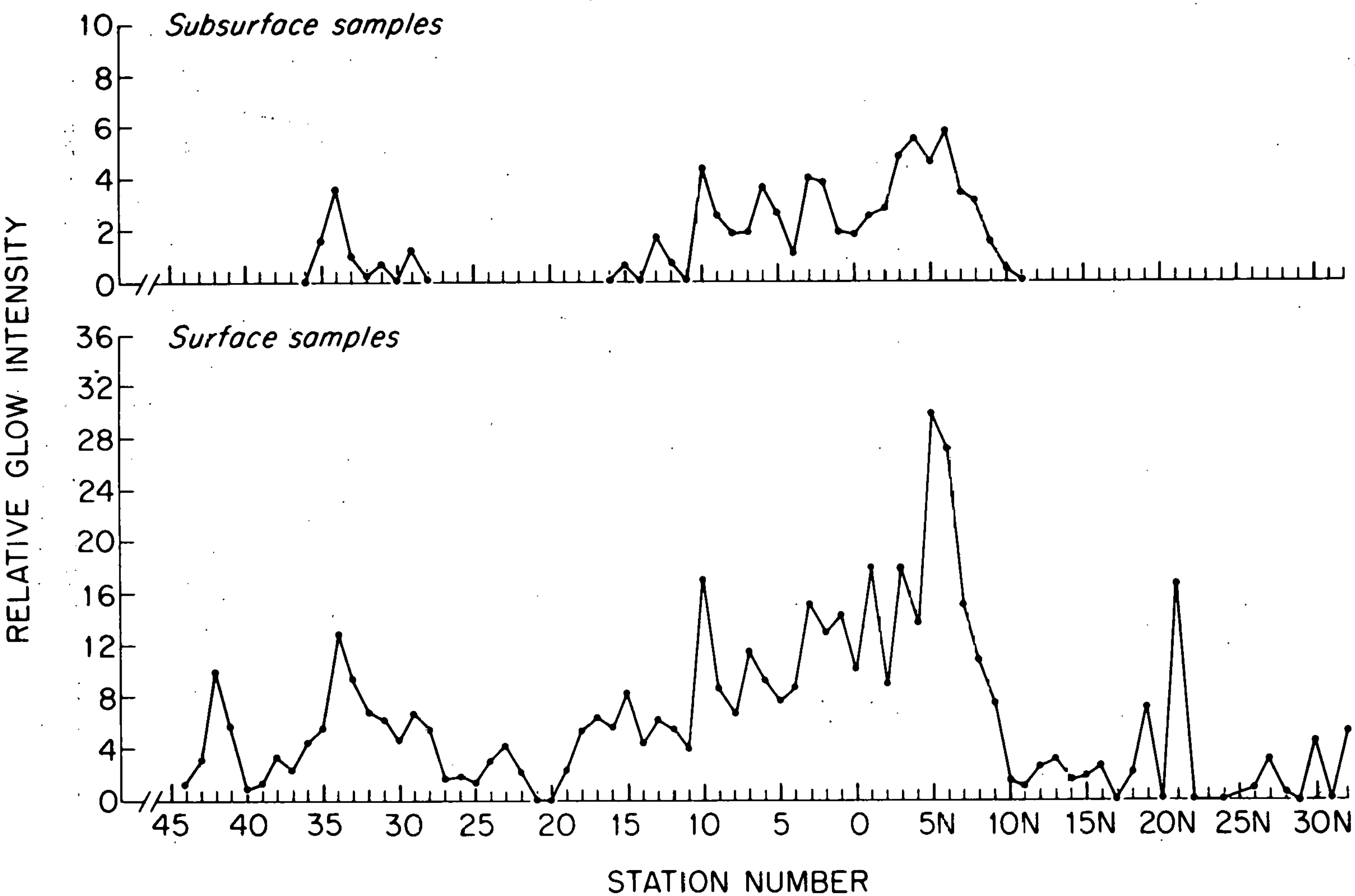

Fig. 7. Thermoluminescence induced in surface and subsurface samples of native soils at each dosimeter station.

soils in the figures indicates that the peak gamma irradiation occurred at station No. 6N. This is in agreement with the TLD-100 LiF dosimeter readings (Fig. 3). In agreement with the TLD-100 readings, the soils also showed peaks of relatively high gamma exposures at stations 34 and 10. Additionally, the peak shown by TLD-100 readings around stations 2 and 3 (Fig. 3) occurred as prominent peaks with soil No. 4FF and the native soils.

A comparison of the results for the subsurface and surface soils shows three notable effects. First, the high peaks for the surface soils did not necessarily correspond with those for the subsurface soils. Second, at each corresponding station, the subsurface soils showed a much lower amount of induced thermoluminescence than the surface soils. Third, the number of dosimeter stations showing induced thermoluminescence was much smaller for subsurface soils than for surface soils.

The lack of correspondence of the thermoluminescence peaks of the subsurface and the surface soils is explained by the non-uniform deposition of the radioactive fallout at the surface. This factor is quite important from the standpoint of beta exposure, since the range of beta particles is small compared to that of gamma photons. The lower thermoluminescence of the subsurface soils is explained by their reduced exposure to radiation due to the attenuation of the gamma photons and the virtual elimination of the beta particles by the 4-inch layer of soil. In addition to these factors, the number of dosimeter stations at which the soils showed induced thermoluminescence depended on the kind of soil. The non-calcareous Hanford sandy loam showed measureable induced thermoluminescence at the greatest number of stations. The highly calcareous soil No. 4FF, on the other hand, showed the greatest amount of thermoluminescence, but at the same time, showed the least number of stations at which the induced thermoluminescence could be definitely ascertained. This was because of the wide variation of the readings made on this soil. At 4-inch depth in the soil, the minimum detectable exposure level was 137 and 308 R with Hanford sandy loam and soil No. 4FF, respectively. These differences between the soils were due primarily to the inhomogeneous distribution of lime in the soil No. 4FF. In view of the small sample size (30 mg) taken for measurement, the inhomogeniety of the lime content can have an appreciable effect, since lime produces relatively very large amounts of thermoluminescence on irradiation compared to other substances ordinarily

found in soils (2). For any given sample, five replicate readings on soil No. 4FF showed a wide standard deviation (± 11.8 relative intensity) compared to that (± 0.9) for Hanford sandy loam.

3.4 SOIL THERMOLUMINESCENCE IN RELATION TO RADIATION EXPOSURE

The relationship between radiation exposure as determined with TLD-100 dosimeters and thermoluminescence at 4-inch depth in the soil is shown in Figure 8. The correlation coefficients were 0.89, 0.78, and 0.93 for the native soils, soil No. 4FF and Hanford sandy loam, respectively. The 0.95 confidence limits for the true correlation coefficients were (0.78, 0.95), (0.52, 0.93), and (0.86, 0.96) for the native soils, soil No. 4FF and Hanford sandy loam, respectively. The higher correlation coefficients shown by the native soils and Hanford sandy loam indicate that slightly calcareous and non-calcareous soils would be better for use as radiation dosimeters than highly calcareous soils. With highly calcareous soils like soil No. 4FF, averaging more replicate readings or reading larger sample sizes might increase the correlation coefficient.

A comparison of the slopes of the lines fitted by the least square methods shows that the rate of induction of soil thermoluminescence in the slightly calcareous native soils was approximately the same as in the non-calcareous Hanford sandy loam. The greater slope of the line for soil No. 4FF support the relatively high thermoluminescent property of highly calcareous soils observed previously (2).

The relationship between radiation exposure as determined with TLD-100 irradiated at 4-inch depth in the soil and the surface soil thermoluminescence was poorer than that indicated above. The correlation coefficients under this comparison were 0.80, 0.53, and 0.75 for the native soils, soil No. 4FF and Hanford sandy loam, respectively. These results were expected, since the TLD-100 rods were exposed only to gamma photons, whereas the surface soil was exposed to variable amounts of both beta particles and gamma photon radiations. Although poorer, the fair correlation shown in this comparison may suggest that gamma photon radiation had the greater effect in inducing thermoluminescence in the surface soils than beta particle radiations.

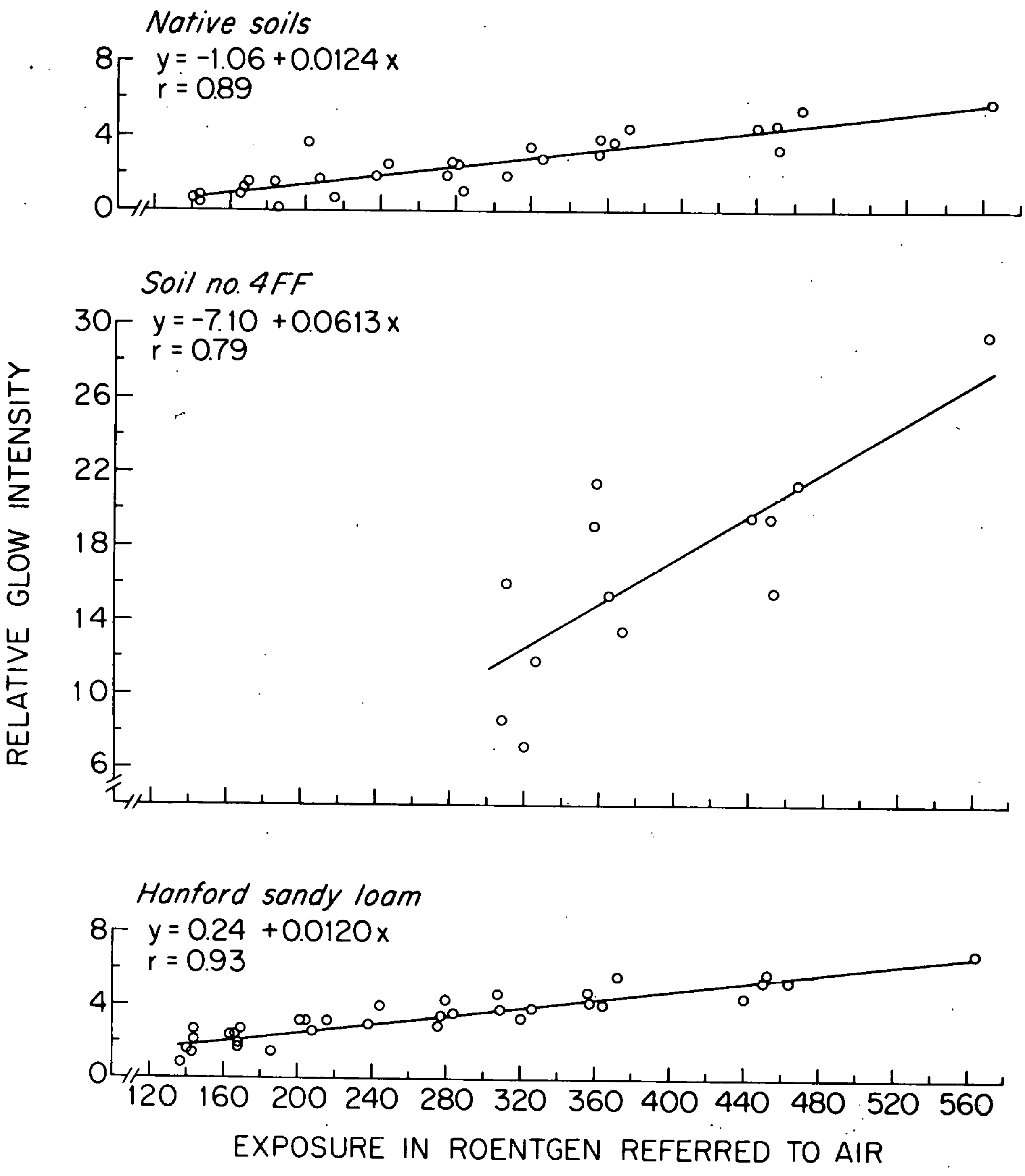

Fig. 8. Thermoluminescence in relation to radiation exposure at four-inch depth in the soil.

No attempt was made to compare the surface soil thermoluminescence with the surface dosimeter readings, because of the variability of the dosimeter readings, as well as the soil thermoluminescence. These variations were caused by the non-uniform and unequal deposition of the radioactive fallout on the soil and the dosimeter packets.

4. CONCLUSIONS AND DISCUSSION

The good correlation between soil thermoluminescence and TLD-100 dosimeter readings indicates that soils might be used to estimate radiation exposure in an area contaminated with relatively large amounts of radioactive fallout from a nuclear detonation. Non-calcareous and slightly calcareous soils appeared to be quite suitable for this purpose. The highly calcareous soils appeared to be less suitable. With highly calcareous soils, the precision of measurement of their "natural" and post-irradiation thermoluminescence was considerably poorer than with non-calcareous or slightly calcareous soils. Consequently, certain precautions must be taken when using them.

Because of the presence of variable amounts of "natural" thermoluminescence in soils, there is a definite restriction in the procedure that can be followed in determining the induced thermoluminescence at any given site. It is necessary to make pre-irradiation collection of the soil, which can then be used to determine the amount of its "natural" thermoluminescence. The soil collected before irradiation may be used also to determine its thermoluminescent decay characteristics after irradiation and to determine the "equivalent" exposure level of the unknown irradiated soil. The decay characteristics may be obtained by studying the decay of the soil exposed to a known radiation source or by following the decay of the field sample collected soon after irradiation. The "equivalent" exposure level of the post-irradiation soil from the field might be estimated by comparing its thermoluminescence against the calibration curve obtained by exposing the pre-irradiation soil to various amounts of radiation from a known source. Experiments to test these procedures are in progress.

5. RECOMMENDATIONS

In areas contaminated with radioactive fallout, the soil is exposed to both beta particles and gamma photons having wide ranges of energy levels. Under these conditions, it is necessary to have the following information in order to assess the accuracy of the radiation exposure estimations: (1) the relative effectiveness of the beta particles and gamma photons in inducing soil thermoluminescence and (2) the degree of dependence of soil thermoluminescence upon the energy levels of the beta particles as well as gamma photons. Thus, investigations along these lines appear to be necessary.

Another aspect that may merit examination is the thermoluminescence of the various components of the soil. By using certain isolated soil components, the precision and the sensitivity of the exposure estimation might be improved, particularly in a highly calcareous soil like No. 4FF.

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1	UNIVERSITY OF ROCHESTER (KAPLON) (AEC)
1	UNIVERSITY OF TENNESSEE (AEC)
1	UNIVERSITY OF WASHINGTON (AEC)
1	WASHINGTON STATE UNIVERSITY (AEC)
1	WESTINGHOUSE ELECTRIC CORPORATION, (WAL) (AEC)
32	AEC DIVISION OF TECHNICAL INFORMATION EXTENSION
25	CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION